U.S. ARMY

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Analysis

RENEWABLE ENERGY ANALYSIS FOR STRATEGIC RESPONSIVENESS

DECEMBER 2001

CENTER FOR ARMY ANALYSIS
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FORT BELVOIR, VA 22060-5230

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 074-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503			
1. AGENCY USE ONLY (Leave blank)	**2. REPORT DATE** December 2001	**3. REPORT TYPE AND DATES COVERED** Final, - December 2001	
4. TITLE AND SUBTITLE Renewable Energy Analysis for Strategic Responsiveness (REASR)			**5. FUNDING NUMBER**
6. AUTHOR(S) Mr. Hugh Jones			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Center for Army Analysis** **6001 Goethals Road** **Fort Belvoir, VA 22060-5230**			**8. PERFORMING ORGANIZATION REPORT NUMBER** CAA-R-01-80
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Assistant Chief of Staff for Installation Management ATTN: MG Robert VanAntwerp 600 Army Pentagon Washington, DC 20310-0600			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES Co-sponsored by the Deputy Chief of Staff for Logistics, Logistics Integration Agency, 500 Army Pentagon, Washington, DC 20310-0500			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; dissemination unlimited			**12b. DISTRIBUTION CODE** A
13. ABSTRACT *(Maximum 200 Words)* The purpose of this project was to conduct an analysis of Army photovoltaic (PV) systems in support of both sustaining base and deployed missions at different locations. This project investigated the value added of PV as a complement to generator power and, in particular, to see whether PV as a renewable energy source can increase operational effectiveness and reduce logistic support and maintenance.			
14. SUBJECT TERMS Photovoltaics (PV), renewable energy, value added			**15. NUMBER OF PAGES**
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	**18. SECURITY CLASSIFICATION OF THIS PAGE** UNCLASSIFIED	**19. SECURITY CLASSIFICATION OF ABSTRACT** UNCLASSIFIED	**20. LIMITATION OF ABSTRACT** SAR

NSN 7540-01-280-5500
Standard Form 298

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RENEWABLE ENERGY ANALYSIS FOR STRATEGIC RESPONSIVENESS

SUMMARY

THE PROJECT PURPOSE was to conduct an analysis of Army photovoltaic (PV) systems in support of both sustaining base and deployed mission contingencies. This project investigates the value added of PV as a complement to generator power and, in particular, to see whether PV as a renewable energy source can increase operational effectiveness and reduced logistic support and maintenance.

THE PROJECT SPONSORS were the Assistant Chief of Staff for Installation Management (ACSIM) and the Deputy Chief of Staff for Logistics (DCSLOG) (Logistics Integration Agency (LIA)), Headquarters, Department of the Army.

THE PROJECT APPROACH was to evaluate PV in terms of:

(1) Operational readiness.

(2) Energy savings.

(3) Pollution prevention.

(4) Economics.

THE SCOPE OF THE PROJECT demonstrated and analyzed a 3-kilowatt (kW) PV system at various continental United States (CONUS) locations during different seasons and under changing meteorological conditions.

THE MAIN ASSUMPTION was that PV has the potential to support Army Transformation by tools and technologies which (1) enhance strategic responsiveness, (2) reduce the combat support/combat service support (CS/CSS) logistics footprint, and (3) reduce the cost of logistics without reducing warfighting capability or readiness.

THE PRINCIPAL INSIGHTS are that PV can**:**

(1) Support unit and installation applications. This is based on after action reports from soldiers engaged in field exercises and installation demonstrations using PV.

(2) Improve operational readiness through reduced operational and maintenance costs.

(3) Help to reduce logistics footprint primarily through lower fossil fuel usage rates.

(4) Produce tactically quiet and uninterruptible power by leveraging thin-film, photovoltaic science.

(5) Complement fossil fuel generators and be part of a suite of portable power sources as sponsored by the Corps of Engineers, Project Manager for Mobile Electric Power.

(6) Be less effective in inclement weather and in poor solar locations.

THE PROJECT EFFORT was conducted by Mr. Hugh Jones, Resource Analysis Division, Center for Army Analysis (CAA).

COMMENTS AND QUESTIONS may be sent to the Director, Center for Army Analysis, ATTN: CSCA-RA, 6001 Goethals Road, Suite 102, Fort Belvoir, VA 22060-5230.

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1 INTRODUCTION

1.1 Renewable Energy Analysis for Strategic Responsiveness

This project was done for the office of the Assistant Chief of Staff for Installation Management (ACSIM) and for the Deputy Chief of Staff for Logistics (DCSLOG) (Logistics Integration Agency (LIA)). The work included field demonstrations of photovoltaics at Waimea, HI, Fort Bragg, NC, and Ft. Stewart, GA.

The term photovoltaics (PV) is derived from two words: photo meaning "light" and voltaics meaning "energy." Photovoltaics, then, is the process of converting light energy into both direct current (DC) and alternating current (AC) for use by soldiers in the field and at installations. The glossary found at the end of this report can further aid the reader.

Renewable energy is defined for this project as any energy source which, through nature, can renew itself on a time scale of 24 hours. In the case of PV, because it uses the natural energy from the sun on a daily basis, it qualifies as a source of renewable energy. On the other hand, fossil fuels, because they take much longer than 24 hours to produce in nature, would not be an example of renewable energy.

1.2 REASR Purpose

To conduct an analysis of Army photovoltaic (PV) systems in support of different missions and at different locations. This project will analyze PV value added in both sustaining base and deployed mission contingencies.

Figure 1. REASR Purpose

The Army is currently engaged in numerous efforts to increase strategic responsiveness while simultaneously reducing logistic support requirements. This project investigates the value added of PV as a complement to generator power, and, in particular, to see whether PV as a renewable energy source can increase operational effectiveness and reduce logistic support and maintenance.

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2 BACKGROUND

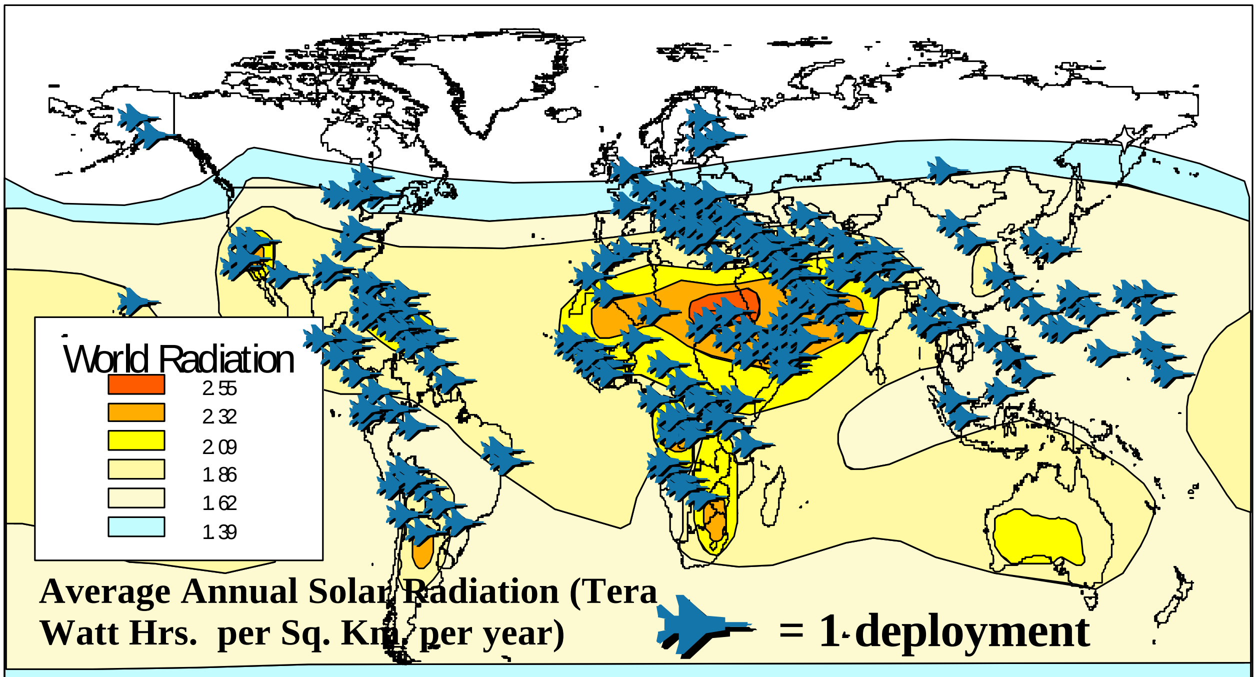
2.1 Analysis of Deployable Applications of PV in Theater (ADAPT): Findings

Figure 2. Analysis of Deployable Applications of PV in Theater (ADAPT): Findings

In 1999, CAA conducted a study entitled the Analysis of Deployable Applications of PV in Theater (ADAPT). This PV proof of concepts demonstration was held at Ft Bragg, NC with the 3/504th Parachute Infantry Regiment (PIR) of the 82d Airborne Division, XVIII Airborne Corps.

The key finding from this field demonstration was that with some modifications of the deployable unit, PV could be used to provide the primary power for a battalion-sized airborne infantry tactical operations center. For their part, the 3/504th provided a written after-action report (AAR) detailing those modifications that would enhance the operational readiness of mobile Army PV.

2.2 US Military Deployments: 1989-1999



Two-thirds of smaller-scale contingencies (SSCs) have been in regions with solar conditions equal to or better than Ft. Bragg.

Figure 3. US Military Deployments: 1989-1999

Let us continue to examine the relationships between solar radiation and geographical location (to include altitude) that significantly impact PV applications. First, PV works better in areas where solar insolation values are high. The highest solar insolation can be found at locations on or near the earth's equator.

Figure 3 shows the last 10 years of US military deployments broken down by major command. Note from the figure that over 60 percent of all deployments have been to areas that were at least equal to or better than the solar radiation found at the demonstration sight at Ft. Bragg, North Carolina.

This illustration was based on over 200 deployments during the past decade. Half of these deployments were to the highest sun radiation areas in or near the Persian Gulf. Solar radiation in these areas is between 2.32 and 2.55 terawatts (tera = trillion) per year per square kilometer (km^2).

The ADAPT project demonstrated PV capabilities to army units that support PV as a viable power potential alternative.

3 ARMY PV SYSTEMS

3.1 First Prototype – 3 kW PV Array

Demonstration Prototypes

As a result of the Analysis of Deployable Applications of Photovoltaics (ADAPT), deployable PV systems have been acquired for demonstration and analysis by the Army at Ft. Bragg (plus deployments) Europe, and Hawaii in support of REASR

PV Analysis:

- Operational
- Environmental
- Energy
- Economic

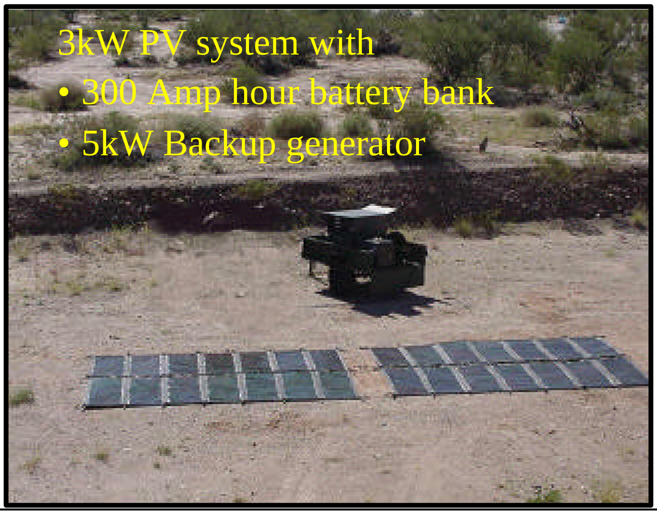


Figure 4. Army Photovoltaic (PV) Systems

There are two versions of the PV system pictured in Figure 4. The first houses a 300-amp hour battery bank with a 5kW PV array and fossil fuel generator. This variant is mounted on an Army M101 ¾-ton trailer.

The second type includes a 600-amp hour battery bank and is mounted on an Army M105 3-ton trailer. Both PV system variants have been deployed and exercised in various locations and in all types of weather conditions by various Army forces.

Five of the six PV systems that have been built to date operate with 110V standard power. The sixth PV system was built to invert DC to AC power at 220V, 50 cycles (hertz). This application was for the European theater where equipment--bought off the local economy--operates in the 220V range.

Although PV is very quiet and does not emit a heat signature, as a target, the PV array which was demonstrated (see Figure 4) was not camouflaged and had to be laid flat on the ground to avoid ground detection. Recent developments by Sandia National Laboratories and by the US Army's Communication and Electronics Command (CECOM) show promise to develop either injected

camouflage dye into the PV cells themselves (CECOM) or else to cover the PV modules with a gel-like substance (Sandia National Labs) to enhance performance and to provide system camouflage.

3.2 REASR Players

- Army Assistant Chief of Staff for Installation Management
- Army Deputy Chief of Staff for Logistics
    - Logistics Integration Agency
- XVIII Airborne
- Army Materiel Command (Science Advisor)
  US Army Europe and 7th Army
- Defense Advanced Research Projects Agency
- Center for Army Analysis

Figure 5. REASR Players

This project involved several sponsors and users of this photovoltaic power generation alternative. This was a joint sponsorship by the Deputy Chief of Staff for Logistics and the Assistant Chief of Staff for Installation Management. Users of the PV systems have been from the XVIII Airborne Corps and 7th Army (Europe).

3.3 REASR Scope

Phase 1:

1. Pacific Rim (Rimpac)
   30 May – 6 July, 2000
   - UN, Joint (US military) & combined (allied) military exercise
   - Provide remote electric power for Humanitarian Assistance / Disaster Relief, Kona, HI
   - Demo of prototype Army PV System
2. Field Training Exercise (FTX)
   Feb 1-20, 2001
   - OPTEMPO Training at Ft. Bragg, NC
   - Incorporation of PV "lessons learned" from Rimpac
3. Operation "Marne Focus"
   Apr 1-20, 2001
   - Ft. Stewart, GA Operational "go to war" exercise & prep for NTC rotation
   - CONUS transport of PV Systems by military

Phase 2:

1. Additional missions and deployments (e.g., NTC, Germany)
2. Strategic Lift (C-130, C-5A, C-17, load plans)
3. Investigate economic factors
   - expensive thin-film technology
   - economies of scale factors
   - industrial base's capabilities to produce thin film

Figure 6. REASR Scope

Pacific Rim Exercise. The PV contractor, Global Solar, was assisted by the US Navy in shipping the Army PV system from Global's manufacturing facility in Tucson, AZ to the exercise location near Kona, Hawaii. Strategic responsiveness and deployability on site were key to the system's success in providing the first remote AC power to various activities at the exercise site.

Although the military force at the exercise site consisted of soldiers and sailors from various military organizations worldwide, the primary military presence was the United States Marine Corps. The Marines provided operational insights, commentary, and constructive criticism on the Army's PV system during the course of the exercise

Field Training Exercise. This exercise, held at Ft. Bragg in February 2001, implemented the lessons learned from the Pacific Rim Exercise (see above). This mission utilized the PV system as mounted on an Army ¾-ton trailer, nomenclature M101.

Operation "Marne Focus." Located at Ft. Stewart, GA, this exercise used PV in heavily forested areas and in very windy and rainy weather. This exercise was the first continental US (CONUS) deployment of the PV System and it survived the transport very well (e.g., slightly bent power inverter door, broken data port).

3.4 REASR Approach

Evaluate PV in terms of:

- Operational Readiness / Strategic Responsiveness (military assessment)
  - Deployability
  - Agility
  - Versatility
  - Sustainability
  - Maintainability
- Energy Savings (gal)
- Pollution Prevention (lb)
- Economics ($$$) - Phase II

Figure 7. REASR Approach

The approach leveraged critical Army in-the-field demonstrations and employed standard energy and pollution analyses. Soldiers provided the operational readiness analysis and included lessons learned for refinements in future PV systems.

The economic analysis will be conducted in REASR II which is scheduled for completion in June 2002.

4 CASE STUDIES

4.1 Case Study # 1: Pacific Rim Findings

- Army PV system *could be used to provide the primary power* source for a battalion-sized Marine Amphibious Force. (TOC & briefing tents)
- Prototype provided 75 % of required remote power for command area from PV System
- Bad weather and volcanic dust degraded PV effectiveness by 20%
- Saved an average of 18 gals of JP-8 /day (PV was alternate for 10kW Tactically Quiet Generator)
  - Estimated yearly OPTEMPO fuel savings: 1,200 gals
  - Estimated yearly OPTEMPO pollution reduction: 2,600 lbs
- Logistics footprint of PV prototype was too large and heavy. Resulted in a redesign that cut weight and volume by 50%

3d Marines AAR (16 June '00)

Figure 8. Case Study # 1: Pacific Rim Findings

The first demonstration event for tactical PV was in June of 2000. This mission was a joint military and United Nations event. The scenario was to provide aid and comfort to a mock disaster, with over 1,000 civilians acting the part of refugees.

Although the exercise was administered by the US military, it was funded by the World Health Organization, the Red Cross, CARE, and miscellaneous refugee welfare organizations.

The US Marine Corps provided all of the necessary aid and comfort facilities for the 2-week exercise. Power was supplied to this effort by two military standard, 10kW diesel generators and the Army PV system.

Weather during the exercise was rainy with volcanic dust blowing most of the time. The dust covered the PV arrays and needed to be swept off at least once every 4 hours. Air filters for the diesel generators were replaced every 2 days.

Although this first demonstration of thin-film photovoltaic array material was successful, the power inverter and battery housing proved to heavy and bulky for strategic deployments. The following 5 months were devoted too reducing weight and volume of the entire PV system. By December of 2000 the system's weight and volume had been trimmed by 50 percent.

4.2 Case Study #2: Field Training Exercise Findings

- 3kW PV system was sole power source for airborne regiment's tactical operations center (TOC, briefing tent)
- Provided tactical quiet for security missions
- Provided 75% of required power from PV system
- Problems with PV system noted
  - – confusing electric switches (fix: switches were better labeled and/or removed)
  - – unclear system default settings (fix: better documentation)
  - – low array efficiency (fix: improved technology in array manufacture)
- Bad weather (rain & overcast for ½ the exercise) degraded PV by 5%
- Saved an average of 11 gals of JP-8 /day (PV system was alternate for 5kW tactically quiet generator)
  - – Estimated yearly OPTEMPO fuel savings: 700 gals.
  - – Estimated yearly OPTEMPO pollution savings: 1,400 lbs

1st 504th PIR AAR (15 February '01)

Figure 9. Case Study #2: Field Training Exercise Findings

In February of 2001, the 1st Battalion of the 504th Parachute Infantry Regiment used a PV system as the main power source during a preparatory training exercise prior to deployment to the National Training Center (NTC). During this demonstration, there were alternative fossil fueled generators available, but were not utilized by the soldiers in the field. There were two reasons for this:

(1) The silent running of the PV when compared to the fossil fuel generators provided stealth for ground troops.

(2) PV provided continuous power without unplanned power interruptions due to the lack of fossil fuel (e.g., maintenance problems or fossil fuel generator failures, late fuel deliveries, forgetting to fill up the fossil fuel generator's fuel tank).

However, there were notable problems with the PV system as well. These included too many possible electric switch settings regarding the power inverter (going from DC to AC power) and unclear system default settings. Both of these problems were addressed following this exercise by reducing the number of switch settings available to the soldier in the field and by clarifying written documentation about resetting the system's default settings.

Additionally, low array yield efficiency was noted and recognized by the contractor, Global Solar Energy. These sub-par PV modules were returned to the vendor and remanufactured in time to support the next exercise (see "Marne Focus").

4.3 Case Study #3: Marne Focus Findings

- 3kW Army PV system used as prime power for 1st Bde 82d AB DIV command center
- Provided uninterruptible, tactical quiet for security missions
- Provided 80% of required power from PV system
- Bad weather (rain & overcast for ½ the exercise) degraded PV by 5%.
- Some minor equipment damage in transit (broken door, bent inverter housing)
- Reduced demand for generator maintenance
- Saved an average of 18 gals of JP-8 /day (PV was alternate for 10kW tactically quiet generator)
  - Estimated yearly OPTEMPO fuel savings: 1,200 gals.
  - Estimated yearly OPTEMPO pollution reduction: 2,600 lbs

1st 504th PIR AAR (20 April '01)

Figure 10. Case Study #3: Marne Focus Findings

The Marne Focus training exercise was the first time that soldiers were entirely responsible for the transport, maintenance, and running of the PV system. And although support was available to them at all times, they called the contractor only once to troubleshoot an electrical shorting problem.

This exercise was also notable because of the extremely poor weather (rain and cloudy for half of the entire exercise time) and because of the forested location. As a result of the rain clouds and wind, the PV's efficiency was degraded by 5 percent from the power it could have provided had the weather been fair to good.

Even with the degraded conditions, the soldiers were able to achieve 80 percent of the required power from the PV system (the remainder came from the fossil fuel generator).

Marne Focus was a turning point for the demonstrations run to date because it instilled a certain level of confidence in the troops' own ability to maintain and to execute the required continuous, silent power of a battalion-sized tactical operations center. There was only one occasion during this 2-week exercise where the contractor had to physically come to assist.

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5 PRINCIPAL INSIGHTS

5.1 Concluding Remarks

- What have we learned from REASR? PV can:
    1. support unit and installation applications
    2. improve operational readiness
    3. help to reduce logistics footprint
    4. produce tactically quiet and uninterruptible power
    5. complement generators and be part of a suite of portable power sources – fuel cells, PV, thermal PV, wind . . .
    6. be less effective in inclement weather and in poor solar locations

- REASR sponsors (LIA and ACSIM) are beginning to investigate the process to institutionalize PV Armywide.

Figure 11. Concluding Remarks

As briefed to the Director of the Logistics Integration Agency, the REASR analysis went beyond the proof of concept stage that was evident in the Analysis of Deployed Applications of Photovoltaics in Theater (ADAPT) and began to analyze both the operational effectiveness and phases of the demos.

REASR also gathered data in three different demonstrations from three different CONUS locations with troops in the field providing after-action reports used to improve the next PV system prototype.

These reports showed that soldiers in the field received added value from PV because the PV System:

(1) Provided continuous, reliable power.

(2) Provided total quiet while running.

(3) Reduced maintenance of the military standard generators.

(4) Reduced the consumption of JP-8.

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APPENDIX A PROJECT CONTRIBUTORS

1. PROJECT TEAM

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Mr. Hugh Jones, Resource Analysis Division

b. Team Members

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Mr. James Keller

c. Other Contributors

Mr. Mark Ricks

2. PRODUCT REVIEWERS

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Ms. Nancy M. Lawrence, Publications Center

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APPENDIX B REQUEST FOR ANALYTICAL SUPPORT

PART 1

Performing Division: RA ***Account Number:*** **2000160**

Tasking: Verbal ***Mode (Contract-Yes/No):*** No

Acronym: **REASR**

Title: Renewable Energy Analysis for Strategic Responsiveness

Start Date: 21-Apr-00 ***Estimated Completion Date:*** 31-Oct-00

Requestor/Sponsor (i.e., DCSOPS): ***Sponsor Division:*** FD/LIA

Resource Estimates: ***a. Estimated PSM:*** 6 ***b. Estimated Funds:*** $0.00

c. Models to be Used: **Hybrid Optimization Model for Electric Renewables**

Description/Abstract:
Provide investment analysis of photovoltaic and other renewable energy alternatives.

Study Director/POC Signature: ***Original Signed*** ***Phone#:*** 703-806-5389

Study Director/POC: **Mr. Hugh Jones**

If this Request is for an External Project expected to consume 6 PSM or more, Part 2 Information is Not Required. See Chap 3 of the Project Directors' Guide for preparation of a Formal Project Directive.

PART 2

Background: Renewable energy has been studied for a number of years within various Federal Agencies. This work studied, analyzed, and demonstrated photovoltaics (PV) in different Army continental United States (CONUS) and outside continental United States (OCONUS) locations.

Scope: To conduct an analysis of Army Photovoltaic systems in support of different missions during different seasons and at different locations. This project analyzed PV value added in both sustaining base and deployed mission contingencies.

Issues: This work examined four measures: (1) operational readiness, (2) pollution prevention, (3) energy savings, and economics.

Milestones: Demonstrations of PV at Ft Bragg, NC (2), Ft Stewart, GA (1), and Pohakoloa Army Test Facility, HI (1) from June 2000 through May 2001.

Signatures ***Division Chief Signature:*** ***Original Signed and Dated*** ***Date:***

Division Chief Concurrence: Mr. Steven Siegel

Sponsor Signature: ***Original Signed and Dated*** ***Date:***

Sponsor Concurrence (COL/DA Div Chief/GO/SES): ACSIM and DCSLOG

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